



INTERNATIONAL TRANSLATION CENTER, INC.

DECLARATION OF TRANSLATOR

I, Lawrence B. Hanlon, of the International Translation Center, Inc., do hereby avow and declare that I am conversant with the English and German languages and am a competent translator of German into English. I declare further that to the best of my knowledge and belief the following is a true and correct translation prepared and reviewed by me of the document in the German language attached hereto.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the attached patent application or any patent issued thereon.

*Lawrence B. Hanlon*  
Lawrence B. Hanlon

Date:

*April 6, 2001*

4/ppts

Device and process for generation of a  
partly synthesized high-quality signal for  
acceleration of an armature of an electric drive

In order to design high-quality position or speed control for a rotary or linear electric drive it has been customary in the past to control the components directly generating torque or force in the innermost loop, that is, in cascade control [1;2]. The most recent developments [3;4] have shown that on the other hand it is highly advantageous not to control the torque or force generating components of the current volume indicators indirectly but to guide the acceleration of the part propelled, that is, in cascade control. In the case of rotary drives this is the spin of the rotor and in the case of linear drives the linear acceleration of the armature. Hence use of an accelerometer is required for registration of these values, for example, an accelerometer which operates on the Ferraris principle [3;4;5]. For one thing, however, this accelerometer on the whole is characterized by a delay in measurement, albeit a small one. For another, this accelerometer can never be completely rigidly connected to the place engaged by rotary thrust in the case of a rotary drive or by linear thrust in the case of a linear drive. The result of these two facts is that loop limit cycles and/or self-excited oscillations are formed in the cascade control loop for the acceleration [4]. Unless these limit cycles and/or self-excited oscillations are prevented, use of such a cascade control loop is not successful for high-quality position or speed control. A process for suppression of these limit cycles and/or self-excited oscillations in the cascade control loop for acceleration has been proposed for rotary drives [4]. However, this process has the disadvantage that its application is

09/830359-012501

extremely costly and in addition that it reacts with extreme sensitivity to fluctuations in the parameters of the drive.

A partly synthesized signal of high dynamic quality for acceleration of an armature of an electric drive can be generated by means of the device claimed for the invention as proposed here. Cascade control of acceleration can be achieved by means of this signal, to a great extent independently of the parameters of the drive, while limit cycles and/or self-excited oscillations are prevented in this cascade acceleration control loop.

A partly synthesized signal of high dynamic quality can be generated with a device as described in Claims 1-12.

For the purpose of generating a high-quality signal for acceleration of an electric drive, first the acceleration signal  $b_m = \alpha F_g(p)$ , in which  $F_g(p)$  describes the measurement transfer function, is registered and then the torque  $m$  or the propulsive force  $f$  as substitute acceleration signal  $b_{Em} = m$  or  $b_{Em} = f$  and, all losses arising throughout propulsion being disregarded and the basis adopted being that of an absolutely rigid connection of the surface engaged by the thrust of the drive to the place at which the effect used for registration of acceleration is used, is scaled so that the relation  $b_m = \alpha F_g(p) - b_{Em} F_g(p)$  is satisfied. The acceleration signal  $b_m = \alpha F_g(p)$  is taken to a low-pass filter with the low-pass transfer function  $FT(p)$ ; hence the signal  $x = b_m FT(p)$  is present at the output of the filter and the substitute acceleration signal becomes a high-pass filter with the high-pass transfer function  $FH(p) = FT(0) - FT(p)$ .  $F_g(p)$ , adjacent to the output of which is the signal  $y = b_{Em} = \alpha F_g(p) [FT(0) - FT(p) F_g(p)]$ . Lastly, the synthesized signal  $z + y$  is formed; it is used as a substitute signal of high

dynamic quality for the instantaneous armature acceleration value in automatic control of the drive.

For this purpose, in the case of rotary current propulsion the rotary acceleration  $\alpha$  of the rotated armature is registered metrologically by an accelerometer [3;4;5] connected to this armature and preferably operating on the Ferraris principle, and is consequently available as measured acceleration signal  $b_m - \alpha$

$F_g(p)$ .  $F_g(p)$ , with  $F_g(0) = 1$ , here represents the so-called measurement transfer function of the accelerometer. The torque  $m$  of the drive, hereafter designated as substitute acceleration signal  $b_E = m$ , is also registered metrologically and accordingly is available as measured substitute acceleration signal  $b_E = m$ . As is to be immediately perceived, use may of course be made, without impairing the operation of the device claimed for the invention, in place of the torque  $m$  of the drive, also directly of the torque-forming transverse-current components  $i_q$  of the current volume indicator of the rotary current fed winding of the drive as substitute acceleration signal  $b_E = i_q$ . In what follows, as is customary in metrology, it is assumed that on the one hand the measured acceleration signal  $b_m$  and on the other the measured substitute acceleration signal  $b_{Em}$ , all losses occurring in the drive in question being disregarded and a mechanically absolutely rigid connection of the surface of the armature rotated engaged by the torque to the position of the rotated part of the rotary acceleration meter at which the effect used for registration of acceleration is generated being taken as a basis, is each scaled so that the relation  $b_m = \alpha \quad F_g(p) = b_{Em} \quad F_g(p)$  is satisfied. The measured acceleration signal  $b_m$  is delivered to the input of a low-pass filter with the low-pass transfer function  $F_T(p)$ ,  $F_T(0)$  preferably equaling 1. Hence the signal  $x = b_m \quad F_T(p)$  can be received at the output of the low-pass

filter. The measured substitute acceleration signal  $bEm$  is delivered to the input of a high-pass filter with high-pass transfer function  $FH(p) = FT(0) - FT(p) \quad Fg(p)$ . Consequently, the signal  $y = bEm \quad [FT(0) - FT(p) \quad Fg(p)]$  may be received at this high-pass filter. A signal  $z = bm \quad FT(p) + bEm \quad [FT(0) - FT(p) \quad Fg(p)]$  is now formed in accordance with the relation  $z = x + y$ . This synthesized signal is subsequently used as a very high-quality dynamic substitute as the undelayed instantaneous value of the rotary acceleration  $\alpha$  of the rotated armature in automatic control of the drive in question.

In the case of a traveling-wave drive the linear acceleration  $\alpha$  of an armature in linear movement is metrologically registered by means of an accelerometer mechanically connected to this armature, one preferably operated on the Ferraris principle transposed to linear movement, and is accordingly available as measured acceleration signal  $bm = \alpha \quad Fg(p)$ . In this instance  $Fg(p)$ , with  $Fg(0) = 1$ , represents the so-called measurement transfer function of the accelerometer. The linear force  $f$  of the drive, to be designated in what follows as substitute acceleration signal  $bE = f$ , is also registered metrologically and is accordingly available as measured substitute acceleration signal  $bEm$ . As is to be immediately perceived, without impairing the operation of the device claimed for the invention, the transverse-current component  $iq$  immediately forming the linear force of the current volume indicator of the multiphase current-fed winding of the drive may be used as substitute acceleration signal  $bE = iq$ . It is assumed in what follows, as is customary in control engineering, that both the measured acceleration signal  $bm$  and the substitute acceleration signal  $bEm$ , all losses occurring in the drive in question being disregarded and a mechanically absolutely rigid

[illegible]

5

invention, in place of the torque  $m$  of the drive, also directly of the armature current  $i_a$  of the direct-current fed winding of the drive as substitute acceleration signal  $b_E = i_a$ . In what follows, as is customary in metrology, it is assumed that on the one hand the measured acceleration signal  $b_m$  and on the other the measured substitute acceleration signal  $b_{Em}$ , all losses occurring in the drive in question being disregarded and a mechanically absolutely rigid connection of the surface of the armature rotated engaged by the torque to the position of the rotated part of the rotary acceleration meter at which the effect used for registration of acceleration is generated being taken as a basis, is each scaled so that the relation  $b_m = \alpha \quad F_g(p) = b_{Em} \quad F_g(p)$  is satisfied. The measured acceleration signal  $b_m$  is delivered to the input of a low-pass filter with the low-pass transfer function  $F_T(p)$ ,  $F_T(0)$  preferably equaling 1. Hence the signal  $x = b_m \quad F_T(p)$  can be received at the output of the low-pass filter. The measured substitute acceleration signal  $b_{Em}$  is delivered to the input of a high-pass filter with high-pass transfer function  $F_H(p) = F_T(0) - F_T(p) \quad F_g(p)$ . Consequently, the signal  $y = b_{Em} \quad [F_T(0) - F_T(p) \quad F_g(p)]$  may be received at this high-pass filter. A signal  $z = b_m \quad F_T(p) + b_{Em} \quad [F_T(0) - F_T(p) \quad F_g(p)]$  is now formed in accordance with the relation  $z = x + y$ . This synthesized signal is subsequently used as a very high-quality dynamic substitute as the undelayed instantaneous value of the rotary acceleration  $\alpha$  of the rotated armature in automatic control of the drive in question.

The device and the process for obtaining a partly synthesized signal of high dynamic value for acceleration of the armature of a machine is explained in detail in what follows on the basis of an example of a separately excited direct-current machine and with reference to the drawings in Figures 1 to 4.

It is advantageous for design of high-quality position or speed control for a separately excited direct-current machine to control rotary acceleration of the armature rather than the armature current in the innermost loop. For this purpose the rotary acceleration  $\alpha$  of the rotor is registered by an accelerometer, preferably one operating on the Ferraris principle, and is accordingly available as measured rotary acceleration  $b_m = \alpha \quad F_g(p)$ . Block 1 (see Figures 1,2,3, and 4) with transfer function  $F_g(p)$ , with  $F_g(0) = 1$ , describes the so-called measurement frequency response of the accelerometer. The torque  $m$  of the drive, which in what follows is designated as substitute acceleration signal  $b_E = m$ , is also registered metrologically and accordingly is available as measured substitute acceleration signal  $b_{Em}$ . Armature current  $I_a$  of the direct-current-fed armature winding of the drive may, of course, also be used as substitute acceleration signal  $b_E = i_a$  in place of the moment  $m$  of the drive. In what follows, as is customary in control engineering, it is assumed that on the one hand the measured acceleration signal  $b_m$  and on the other the measured substitute acceleration signal  $b_{Em}$ , all losses occurring in the drive in question being disregarded and a mechanically absolutely rigid connection of the surface of the armature rotated engaged by the torque to the position of the rotated part of the rotary acceleration meter at which the effect used for registration of acceleration is generated being taken as a basis, is each scaled so that the relation  $b_m = \alpha \quad F_g(p) = b_{Em} \quad F_g(p)$  is satisfied. The measured acceleration signal  $b_m$  is delivered to the input of a low-pass filter 2 (see Figures 1,2,3, and 4) with the low-pass transfer function  $F_T(p)$ ,  $F_T(0)$  preferably equaling 1. Hence the signal  $x = b_m \quad F_T(p)$  can be received at the output of the low-pass filter. The measured substitute acceleration signal  $i_{bm}$  is delivered to the input of a high-pass filter 3 (see Figures 1 and

2) with high-pass transfer function  $FH(p) = FT(0) - FT(p)$   
 $Fg(p)$ . Consequently, the signal  $y = bEm [FT(0) - FT(p) Fg(p)]$  may be received at this high-pass filter. A signal  $z = bm$   
 $FT(p) + bEm [FT(0) - FT(p) Fg(p)]$  is now formed in  
 accordance with the relation  $z = x + y$ . This synthesized signal  
 is subsequently used as a very high-quality dynamic substitute as  
 the undelayed instantaneous value of the rotary acceleration  $\alpha$  of  
 the rotated armature in automatic control of the drive in  
 question. The difference between the set value  $\alpha_{sol1}$  assigned by  
 a superimposed control system and the synthesized signal  $z$  is  
 delivered to a suitable control unit 4 as control difference (see  
 Figure 1). Delay of the measurement transfer function  $Fg(p)$  and  
 the considerable disturbance of the transfer function  $FM(p)$  are  
 eliminated from the control frequency response, which is of  
 decisive importance for stability, possible limiting cycles, and  
 self-excited oscillations. The last-named transfer function,  
 $FM(p)$ , describes the mechanical frequency response between the  
 surface of the armature moved which is engaged by the thrust of  
 the drive and the position of the moved part of the accelerometer  
 at which the effect used for registration of acceleration is  
 generated. The low-pass filter with low-pass transfer function  
 $F\gamma(p)$  almost entirely eliminates the influence of this mechanical  
 frequency response. So long as transfer function  $FM(p)$  does not  
 deviate significantly from value 1, damping of the low-pass  
 filter does not exhibit significant values. But starting with  
 the limit frequency of the low-pass filter the damping rises  
 sharply, so that the unavoidable resonance step-ups of the  
 mechanical frequency response virtually exert no more influence.  
 The delay of the acceleration signal  $bm$  by the measurement  
 transfer function  $Fg(p)$  and the delay additionally caused by the  
 low-pass filter are entirely eliminated by signal  $y = bEm FH(p)$   
 at the output of the high-pass filter in the frequency response

in question of the control loop formed by means of the synthesized signal  $z$ .

The procedure claimed for the invention as presented is also described by the block diagram in Figure 1. The first-order delay element 5 (see Figures, 1, 2, 3, and 4) with amplification  $VR$  and time constant  $TE$  describes the delayed reaction of the armature current  $i_a$  to change in voltage at the input of the delay element.

In a preferred embodiment the output voltage of the pulse inverter which feeds the armature winding of the drive is derived directly from a two-point control loop [6], on the principle of the discrete-time switching condition control with a clock frequency  $f_A = 1/TA$  in the 100-kHz range. Consequently, in Figure 2 the controller 4 is replaced by the two-point element 6, a scanning element 7 with scanning frequency  $f_A = 1/TA$ , and a zero-order holding element 8. Amplifications  $V$  and  $-V$  in the two-point element 6 take the ratio of converter output voltage to rated voltage of the machine into account. The scanning element 7 and the zero-order holding element 8 allow for the effect of discrete-time switching condition control. In this embodiment of the device claimed for the invention the limit frequency selected for the low-pass filter 2 with low-pass transfer function  $FT(p)$  is to be low enough that no self-excited oscillations occur in the two-point control circuit for synthesized signal  $z$ .

Should the circumstance frequently occurring in practical application that the connection between the measured substitute acceleration signal  $b_{Em}$  and the measured acceleration signal  $\alpha_m$  is only incompletely described by the equation  $\alpha_m - Fg(p) \quad b_{Em}$  prove to be a source of disturbance for the quality of the two-

point cascade control, the process claimed for the invention is expanded. This expansion is characterized by the block diagram in Figure 3. In this instance the transfer function FM(p) 9 describes the mechanical frequency response from the surface of the armature set in movement which is engaged by the thrust of the drive to the position of the part of the accelerometer set in movement at which the effect used for registration of acceleration is generated. The relationship between the substitute acceleration signal bEm and the measured acceleration  $\alpha_m$  is accordingly expressed as  $\alpha_m = FM(p) \cdot Fg(p) \cdot bEM$ . This mechanical frequency response with transfer function FM(p) 9 (see Figures 3 and 4) is now taken into account in that the high-pass filter 3 with high-pass transfer function FH (p) = FT(0) - FT(p)

Fg(p) is replaced by a modified high-pass filter 10 with modified high-pass transfer function Fh(p) = FT(0) - FT(p) Fg(p) FM(p). It is advisable in this process not to determine the limit frequency of the low-pass filter 2 with low-pass transfer function FT(p) until the high-pass filter 3 with high-pass transfer function FH (p) has been replaced by modified high-pass filter 10 with modified high-pass transfer function Fh(p).

Should the transfer function FM(p) have a plurality of polar and/or zero positions, development of the high-pass filter 10 with modified high-pass transfer function Fh(p) is found to be very costly. In order to reduce this cost in development of this high-pass filter 10, the process claimed for the invention may be further modified as described in the following. A part

$$F_0(p) = \frac{(1+p \cdot T_u) \cdot (1+2 \cdot D_v \cdot p \cdot T_v + p^2 \cdot T_v^2) \cdot \dots}{(1+p \cdot T_i) \cdot (1+2 \cdot D_j \cdot p \cdot T_j + p^2 \cdot T_j^2) \cdot \dots}$$

is separated from the transfer function of the mechanical frequency response. This part allows for one or more poles

and/or zero positions with particularly high values of  $T\mu$ ,  $Tv$ ,  $Ti$ , or  $Tj$ . The transfer function of the mechanical frequency response may be described as follows

$$F_M(p) = F_0(p) \cdot F_{M,Rest}(p) \text{ mit } F_{M,Rest}(p) = F_M(p) \cdot F_0^{-1}(p).$$

The mechanical frequency response with transfer function  $F_M(p)$  9 is now taken into account only in approximation by the circumstance that the high-pass filter 3 with high-pass transfer function  $F_H(p) = F_T(0) - F_T(p)$   $F_g(p)$  is replaced by a modified high-pass filter 11 with modified high-pass transfer function  $F_{h^*}(p) \approx F_T(0) - F_T(p)$   $F_{[-]}(p)$   $F_0(p)$ . It is advisable not to determine the limit frequency of the low-pass filter 2 with low-pass transfer function  $F_T(p)$  in this process until the high-pass filter 3 with high-pass transfer function  $F_H(p)$  has been replaced by modified high-pass filter 11 with modified high-pass transfer function  $F_{h^*}(p)$ . The proposed process claimed for the invention is described by the block diagram in Figure 4.

105270 65506550

## [References]

- [1] Leonhard, W., Electric variable speed drives for mechanical engineering, state of the art, trends in development, (Electrische Regelantriebe für den Maschinenbau, Stand der Technik, Entwicklungstendenzen. VDI [Association of German Engineers]-Zeitschrift (1981), No. 10
- [2] Weck, M., Krüger, P., Brecher, C., Remy, F., Statistical and dynamic rigidity of linear direct drives, (Statische und dynamische Steifigkeit von linearen Direktantrieben) antriebstechnik 36 (1997), No. 12, pp. 57-63
- [3] Schwarz, B., Contributions to rapid-reaction and high-accuracy rotary current positioning systems, (Beiträge zu reaktionsschnellen und hochgenauen Drehstrom-Positioniersystemen) Dissertation, University of Stuttgart, 1986.
- [4] Gambach, H. Servo drives with two-point cascade control of their rotary acceleration, [Servoantriebe mit unterlagerter Zweipunktregelung ihrer Drehbeschleunigung], Dissertation, University of Stuttgart, 1993.
- [5] EP 0 661 543 B1, Transmitter system for determination of at least one of three quantities: rotary acceleration, angular velocity, or angular position of a rotating component. [Gebersystem zur Ermittlung wenigstens einer der drei Größen Drehbeschleunigung, Winkelgeschwindigkeit oder Winkellage eines rotierenden Bauteils].
- [6] Boehringer, A., Setting of switching states in power electronics actuators by the directly desired effect [Einstellung der Schaltzustände in Stellgliedern der Leistungselektronik], etzArchiv, Vol. 11 (1989), No. 12, pp. 381-388.